ESTIMATION OF THE MFD ON 47 PREFECTURAL CAPITALS

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1. **Introduction**

Traffic congestion has been a persistent problem. Understanding the characteristics of the Macroscopic Fundamental Diagram (MFD) is crucial for traffic management strategies. Various studies examining the factors that influence the characteristics of the MFDs have been undertaken[1) 2)]. However, there is not much information on how the shape of the MFD is affected by the type of the city such as mega or rural cities and their networks. The main purpose of this study is to understand the characteristics of the MFD shapes in different cities.

2. **Data Description**

This study utilizes the nationwide probe vehicle data collected by the Electronic Toll Collection (ETC) 2.0 system to derive the MFD. The data is aggregated in an hour, and collected over a year from April 2015 to March 2016. It is necessary to standardize the variables of the MFD because the number of samples collected by the ETC 2.0 are increasing every month. The standardized variables, $stQ^{m,d,t}$ and $stK^{m,d,t}$ are calculated as demonstrated in Equation (1) to (4).

$$stQ^{m,d,t} = Q^{m,d,t}/Q^m = \left(\sum_{i \in I^{m,d,t}} q_i^{m,d,t}\right)/Q^m \quad (1) \qquad Q^m = \sum_{d=1}^{D^m}\sum_{t=1}^{T} Q^{m,d,t}/(D^m \cdot T) \quad (3)$$

$$stK^{m,d,t} = K^{m,d,t}/K^m = \left(\sum_{i \in I^{m,d,t}} k_i^{m,d,t}\right)/K^m \quad (2) \qquad K^m = \sum_{d=1}^{D^m}\sum_{t=1}^{T} K^{m,d,t}/(D^m \cdot T) \quad (4)$$

where, $Q^{m,d,t}$:total vehicle kilometers in an area in month m on day d at time interval t, $K^{m,d,t}$:total vehicle hours in an area in month m on day d at time interval t, $q_i^{m,d,t}$: distance traveled in an area by vehicle i in month m on day d at time interval t, $k_i^{m,d,t}$: time spent in an area by vehicle i in month m on day d at time interval t, $I^{m,d,t}$: set of vehicles in an area in month m on day d at time interval t, Q^m :average vehicle kilometers during a unit time interval in month m, K^m :average vehicle hours during a unit time interval in month m, D^m:number of days in month m and T:number of time intervals within a day (i.e., $T = 24$).

3. **Study area**

The analysis was carried out in the 47 prefectural capitals. The study focuses on the central business districts (CBD) of the capital cities; an area of approximately 9km square is selected considering the sizes of the CBD.

4. **Analysis of the MFD Characteristics**

The standardized flow, $stQ^{m,d,t}$, and density, $stK^{m,d,t}$, are calculated for each of the 47 study areas according to Equation 1 and 2. In order to examine the influence of the day of week, the MFD is calculated for weekdays and holidays. Thus, 94 diagrams are available in total. The MFD takes non-linear form with different ranges of density in line with the change in flow. Hence different linear relationships could occur. This study applies a piecewise linear regression (PLR) model (equation 5), which fits regression lines based on the shape of the MFD. The shape is fitted by three line segments with two breakpoints as presented in fig.1. The slopes of each line, β_1, β_2 and β_3 represent the shockwave speed in each traffic state. When density is smaller than the first breakpoint P_1, the network is in the smooth region with free flow. Once density exceeds P_1, the slope changes to β_2, and the traffic state moves to the crowded region where there is slight congestion. When density surpasses P_2 the network is in the most congested state or breakdown region where the slope is β_3.

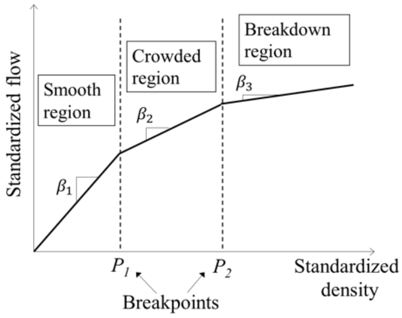

Fig.1 Piecewise linear approximation of the MFD and parameters

$$stQ^{m,d,t} = \beta_1\left(stK^{m,d,t}d_1 + P_1 d_2 + P_1 d_3\right) + \beta_2\left((stK^{m,d,t} - P_1)d_2 + (P_2 - P_1)d_3\right) + \beta_3(stK^{m,d,t} - P_2)d_3 \quad (5)$$

where, P_1, P_2:breakpoints ($P_1 \leq P_2$), d_1 : 1 if $stK^{m,d,t} \leq P_1$, otherwise 0, d_2: 1 if $P_1 < stK^{m,d,t} \leq P_2$, otherwise 0, d_3 : 1 if $stK^{m,d,t} > P_2$, otherwise 0, and $\beta_1, \beta_2, \beta_3$: Slopes of line segments.

The analysis results reveal that the traffic states change as the network density increases, thus the MFDs can be classified into 3 types. The 1st type (fig.2) has 1 breakpoint, the traffic stays in the smooth and crowded region and does not have a breakdown region. The other 2 types (fig.3 and 4) have 2 breakpoints with all the 3 regions. However, β_3 is positive in type 2, while β_3 is negative in type 3, indicating that type 3 has heavier congestion with serious breakdown when density is high. The results suggest that the shape of the MFDs can be attributed by the parameters of the slopes and the breakpoints. Finally, the k-means method is applied to the parameter sets of the MFDs, with the number of clusters being 4 based on the elbow method. The results identify four typical shapes of the MFD. Each cluster includes the cities as summarized in table 1, implying that the shapes of the MFDs could be explained by the characteristics of each cities, such as road network structures and land use types.

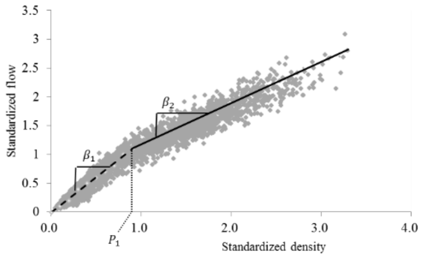

Fig.2 Sample MFD with 2 regions

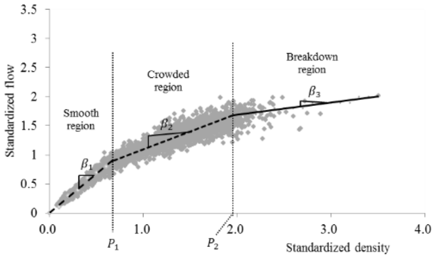

Fig.3 Sample MFD with $\boldsymbol{\beta_3 > 0}$

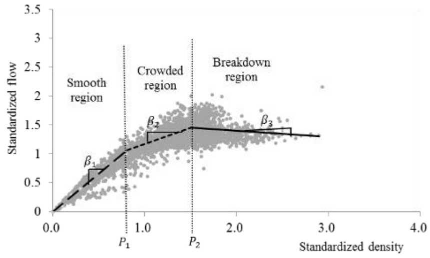

Fig.4 Sample MFD with $\boldsymbol{\beta_3 < 0}$

Table 1. MFD clustering results

Cluster	Day of week	Prefectures
1	Weekday	Hokkaido, Iwate, Akita, Tokyo, Kanagawa, Niigata, Kyoto, Wakayama, Kagawa, Ehime, Fukuoka, Nagasaki, Miyazaki, Kagoshima, Okinawa.
	Holiday	Aomori, Fukushima, Tochigi, Saitama, Chiba, Tokyo, Shiga, Kyoto, Hyogo, Okinawa.
2	Weekday	Aomori, Miyagi, Yamagata, Tochigi, Ibaraki, Gunma, Saitama, Ishikawa, Fukui, Yamanashi, Nagano, Shizuoka, Mie, Osaka, Nara, Tottori, Shimane, Okayama, Yamaguchi, Saga, Kumamoto.
	Holiday	Hokkaido, Iwate, Miyagi, Akita, Yamagata, Ibaraki, Gunma, Kanagawa, Toyama, Ishikawa, Fukui, Gifu, Shizuoka, Aichi, Mie, Nara, Wakayama, Tottori, Shimane, Hiroshima, Yamaguchi, Tokushima, Kagawa, Kochi, Fukuoka, Saga, Nagasaki, Kumamoto, Oita.
3	Weekday	Fukushima, Chiba, Toyama, Hyogo, Tokushima, Aichi.
	Holiday	Yamanashi.
4	Weekday	Gifu, Shiga, Hiroshima, Kochi, Oita.
	Holiday	Niigata, Nagano, Osaka, Okayama, Ehime, Miyazaki, Kagoshima.

5. Conclusion

The piecewise linear regression analysis revealed that the traffic states change as the network density increases. The clustering analysis based on the k-means method revealed that the MFDs can be grouped into 4 clusters, each of which takes typical forms of the MFDs in the cluster. Further research is required to understand how the traffic characteristics and infrastructure in the 47 prefectural capitals are affecting the shape of their MFDs. As well, the effects of weathers need to be considered in future works. It is also important to assess how accident risk affects the traffic conditions in these cities.

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Reference

1) Geroliminis, N., & Sun, J. (2011). Properties of a well-defined macroscopic fundamental diagram for urban traffic. *Transportation Research Part B: Methodological*, *45*(3), 605–617.
2) Zhang, L., Garoni, T. M., & de Gier, J. (2013). A comparative study of Macroscopic Fundamental Diagrams of arterial road networks governed by adaptive traffic signal systems. *Transportation Research Part B: Methodological*, *49*, 1–23.